ILLEGIB

Special Projects June 16, 1964.

II GENERAL ANALYSIS

In considering the design of such a filter, a number of possibilities exist. Some of these are:

1. A gradient deposited reflection filter.
2. A gradient exposed photographic filter.
3. A variable thickness colored filter glass.

or

4. A cell consisting of two (2) pieces of glass with a variable void between them, that is filled with a liquid containing a dye that would absorb light at rate equivalent to the liquid's varying thickness.

The fourth method was selected as a parallel effort with the first two listed above. For the remainder of this memo, this method will be referred to as the Liquid Spatial Filter.

Before attempting the fabrication of the Liquid Spatial Filter, a number of parameters and their tolerances were considered to determine the feasibility and practicality of attempting such a design.

The first consideration would be that of phase shift. This phase shift would be caused by the difference in index of refraction between the glass and liquid. The diagram in Figure 2 and the equations accompanying this diagram illustrate the permissible index-of-refraction mismatch between the glass and liquid.

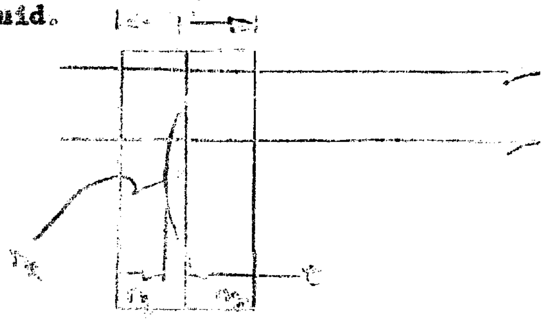

Figure 2.

$P_1 = n_g T$

$P_2 = n_\ell t + n_g (T - t)$

$P = P_2 - P_1 = 1/20\ \lambda$

$n_\ell t + n_g T - n_g t - n_g T = P$

$(n_\ell - n_g) t = 1/20\ \lambda$

$(n_\ell - n_g) t = .032\mu$

selecting $t = 10\mu$

$(n - 1.515)\ 10\mu = .032\mu$

$1.512 \leq n \leq 1.518$

$$\begin{array}{r} .6328 \\ \times .05 \\ \hline .031640\mu \end{array}$$

ΔP = Path Length Difference

T = thickness of cell

t = thickness of liquid

n_g = refractive index of glass = 1.515

n_ℓ = refractive index of liquid

P_1 = Path

through glass and liquid

STAT

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The thickness, t = 10μ, was selected since a mismatch of refractive index of $\pm$.003 was assumed after consulting various handbooks and the temperature considerations outlined below. 10μ was also deemed the minimum reasonable thickness that could be fabricated by the Optical Facility without extreme expense. Also, the filling of this "hole" had to be considered and 10μ was judged the minimum acceptable dimension. 10μ can be measured easily and the accuracy possible was 1%. Thus, 10μ $\pm$.01 is available with moderate ease and a $\pm$.01μ difference is insignificant.

The next consideration was change of refractive index of the liquid with change in temperature(3). It was determined that:

$$\frac{dn}{d\theta} \approx \beta \frac{n^4 + n^2 - 2}{6n}$$

where

n = refractive index

β = coefficient of cubical expansion

= 40.3 x $10^{-5}/^{o}F$ for Methyl Benzoate calculated from data in 41st Edition Handbook of Chemistry and Physics and using density information and equation:

$$d_h = \frac{d_c}{1 + \beta t} \quad (4)$$

$\frac{dn}{d\theta}$ = change of index of refraction with change of temperature.

It should be noted that this equation is a good approximation to determine order of magnitude.

$$\frac{dn}{d\theta} = \frac{40.3 \times 10^{-5}}{1^{o}F} \quad \frac{(1.515)^4 + (1.515)^2 - 2}{6 \ (1.515)}$$

$$= \frac{24.95 \times 10^{-5}}{^{o}F}$$

$$.001 \text{ change in index} = \frac{10 \times 10^{-4}}{2.495 \times 10^{-4}} = 4^{o}F$$

thus, a $\pm 4^{o}F$ temperature shift would shift the index of refraction $\pm$.001. The change of index of refraction with change in temperature for the glass was calculated and found insignificant compared to that of the liquid and, therefore, was ignored.

Thusfar, our calculated values and tolerances appeared reasonable. We had two more calculations and one measurement to make. Using the sag formula:

$$t_o = \frac{c^2}{2R}$$

we solved for R, the radius of curvature by setting,

$$t_o = \frac{r^2}{2R} \quad \text{where r is the clear aperture and } t_o = 10\mu$$

$$R = \frac{r^2}{2t_o} = \frac{(32.85)^2 mm}{2 \times 10\mu} = 53,956 \text{ mm}$$

The next calculation was using Beer's law:

$$I = I_o e^{-\alpha t}$$

where I_o = incident flux, I, the flux passing through a thickness, t, of a material whose absorbtion coefficient is α. For simplicity, I_o was set equal to 1, t = 10μ, I = .04 which is the estimated detectivity of the limiting spatial frequency, which is 200 λ/mm, and α was solved for. Under these conditions, α = 321/mm.

III MEASUREMENTS

From the above calculations, it was obvious that the liquid of index 1.515 ±.003 would have to be made sufficiently opaque so that a 10μ thickness would transmit only 4% of the incident light of wavelength .6328μ. Since this is a red light, a blue dye was selected as an absorption medium. The change of refractive index due to the addition of the dye was not taken into consideration at this time since chemical sources stated that a dye would not change the index of refraction significantly.

At this point, two liquids had been selected:

	$n_{D/20^o}$	$n_{.6328/20^o}$
Ethyl Benzoate	1.5054	1.505
Methyl Benzoate	1.5167	1.516

It had been determined:[5]

$$n = \frac{n_1 \cdot u_1 + n_2 \cdot u_2}{100}$$

where n_1 = index of first fluid, n_2 = index of second fluid;

u_1 = volume of first fluid, u_2 = volume of second fluid.

n = new index due to the mixture of the two fluids.

From the above it is apparent that a perfect glass-fluid index of refraction match is possible. Thus, if the glass-fluid index of refraction match is perfect, and the cell is used in a room where the temperature fluctuation is not more than ±2°F, the t (thickness of fluid) can be as high as 60μ. This is significant since we had no idea of the solubility of the blue dye in these fluids. At this point, we made absorbance measurements using a [redacted] Spectrometer.

Special Projects June 16, 1964.

Methyl Benzoate had 14g/liter of the Acetate Blue dye added and the following data was recorded:

	TRANSMITTANCE	ABSORBENCE NO.
50μ cell	1.2%	1.921
1 mm cell with sample diluted 1:40	1.5%	1.824

From these measurements, the 50μ cell thickness was questioned, and since it was not parallel, it could not be measured using a grating spectrometer. Therefore, the following calculations were made to determine the final concentration of the fluid.

Since the absorbence numbers obtained were at a 50μ cell thickness, by dividing these numbers (i.e., 1.921 and 1.824) by 5, the absorbence number for a 10μ thickness will be determined. From the [redacted] precision table for Conversion of Absorbence to Transmittance the transmittance of the 10μ thickness can be determined. This table is helpful since absorbence is a linear function whereas transmittance is a logarithmic function.

$$5\,\overline{)1.921}^{\;.384} \qquad 5\,\overline{)1.824}^{\;.365}$$

Thus,

	TRANSMITTANCE	ABSORBENCE NO.
10μ	41.2%	.384
	43.2%	.365

Then, by dividing the new absorbence numbers (i.e., 0.384 and 0.365) into the desired absorbence number 1.398 = 4% transmittance, the multiplication factor will be determined for what dye concentration is needed to obtain 4% transmittance.

$$.384\,\overline{)1.398}^{\;3.64} \qquad .365\,\overline{)1.398}^{\;3.83}$$

So the present concentration of 14 g/liter would have to be increased by 3.64 - 3.83.

$$14 \text{ g/liter} \cdot 3.64 = 51 \text{ g/liter}$$

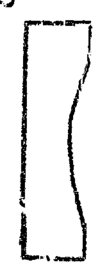
$$14 \text{ g/liter} \cdot 3.83 = 53.6 \text{ g/liter}$$

The solubility did not seem excessive since the 14 g/liter concentration was easily mixed.

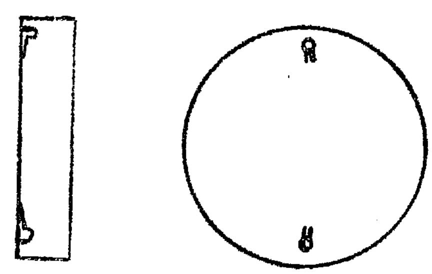
IV FABRICATION AND PRACTICAL EXPERIENCE

A filter was fabricated using a 10μ thickness in order to test out our calculations and determine any further information. Thus, Methyl Benzoate with index 1.576 was used and, allowing for temperature, the 10μ thickness was the best selection. At this writing, tests have been made and the acetate blue dye NDN base, #43306, [redacted] solubility has been a problem for the 10μ thickness. However, Malachite Green diluted in water seems to solve the problem nicely without solubility problems since a concentration of 2-3 g/liter is all that is necessary to obtain the desired transmittance. Methyl Benzoate was in short supply so water was used, but subsequent tests indicated that 2-3 g/liter concentration of Malachite Green in Methyl Benzoate is easily obtainable. Our main problem is filling techniques. Note the accompanying drawings and the two ridges opposite each other on the flat. These are provided for filling and vent purposes. The original idea was to optically contact the flat and the concave element as noted in 581-0062. The reason for optically contacting was that it was considered the best method available to contain the liquid. Then, using a water aspirator or vacuum pump to reduce the pressure in the cavity; the absorbing fluid would be injected by means of a hypodermic syringe. This method was not successful. The main problems that hampered us were insufficient vacuum, air bubbles in the fluid, trapped air while filling, inadequate sealing of the ridges, and air leaking in through the ridges after filling. The next method attempted was an immersion method. We used two pieces of plate glass as illustrated in the diagram below. The main difference was the expansion hole

581-1271



modified 581-1270



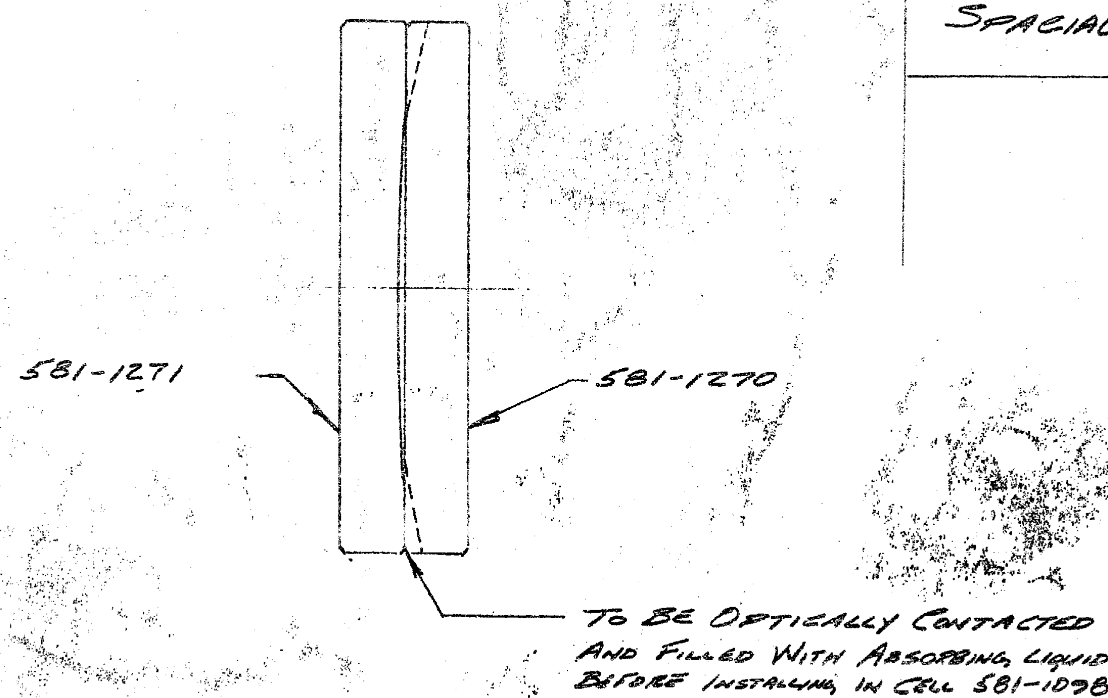
provided at the end of the ridges to allow for bubbles. These pieces were immersed in the absorbing fluid and brought in contact while immersed. The cell was removed from the fluid, dried, and placed in a clamp. Then, the two pieces were bonded using black hysol. This was successful except vapor bubbles appeared and did not always find their way to the expansion hole. These bubbles were eliminated by gently heating the cell for a few hours with a 100 watt light bulb. Since the fluid and glass was at or slightly above room temperature when the cell was filled, it is felt that this vapor bubble problem could be eliminated if the fluid and glass temperature was somewhat lower than the temperature at which it will be used (when filling the cell). At this point, the project was culmina... to the high cost of fabrication of the cell and the difficulties encountered in ass...

V CONCLUSION

Thus, a high performance liquid spatial filter, which at first consideration was deemed difficult, has been fabricated.

DRAWING NO.
581-0062

LIQUID GATE WINDOW
ASSY.
SPACIAL FILTER



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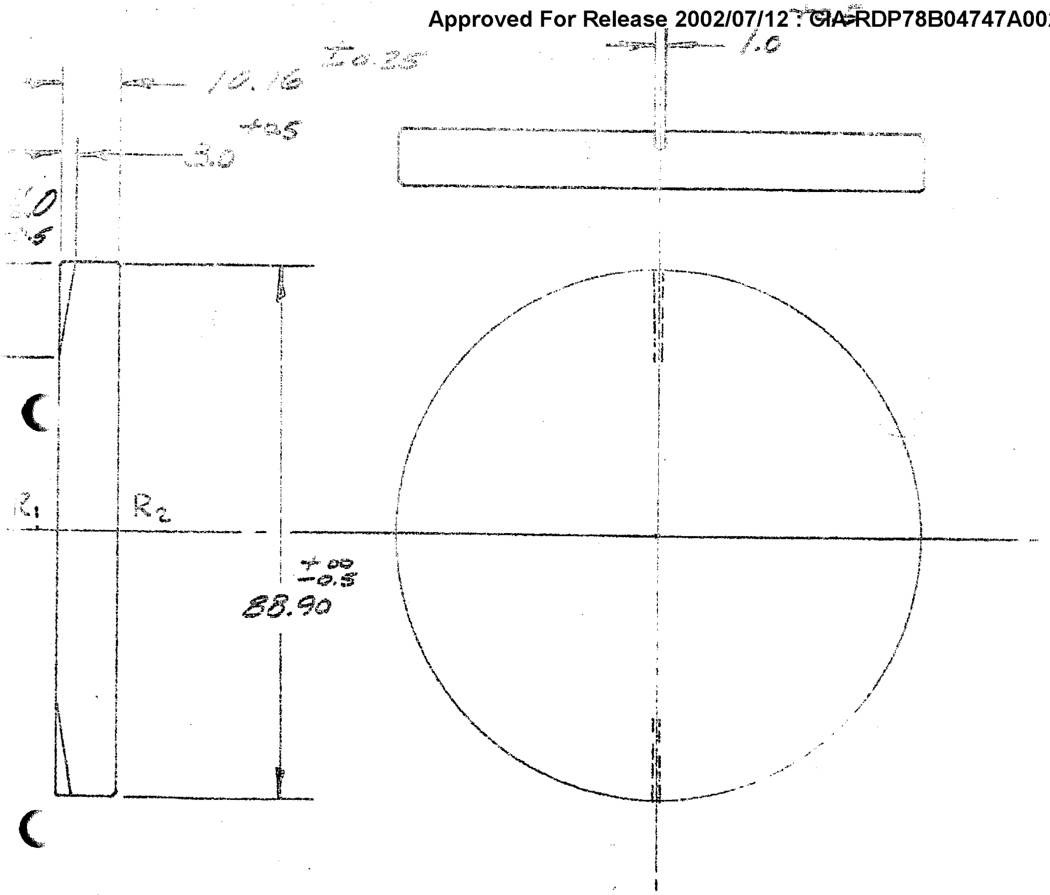
581-1278



LIQUID GATE WINDOW
FOR
SPACIAL FILTER

$N_D = 1.516$

SPEC. OBJECTIVE QUALITY

RADIUS	CC	CX	TOL.	SURFACE CODE	FIGURE TOL.	COATING TYPE	CODE	λ
∞	–	–	1/10λ	20–10	1/4 λ	UNCOATED		
∞	–	–	1/10λ	20–10	1/20 λ	ZERO REFLECTANCE		6328
						0.2 %		

ILLEGIB

Approved For Release 2002/07/12 : CIA-RDP78B04747A002700020027-2

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(3) [redacted] STAT

(4) Hausman & Slack, Physics, P. 220, Library of Congress Catalog Card No. 57-10371

(5) Dr. Otto Jordan, The Technology of Solvents, P. 37, Chemical Publishing Company, 1937 Edition.